

PATENT COOPERATION TREATY

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To: JOHN E. MILLER
CALFEE, HALTER & GRISWORD LLP
800 SUPERIOR AVENUE, SUITE 1400
CLEVELAND OH 44114

PCT

NOTIFICATION OF TRANSMITTAL OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Rule 71.1)

Date of Mailing
(day/month/year)

29 MAR 2001

Applicant's or agent's file reference

21422/04017

IMPORTANT NOTIFICATION

International application No.

PCT/US99/30774

International filing date (day/month/year)

22 DECEMBER 1999

Priority Date (day/month/year)

29 DECEMBER 1998

Applicant

UNIVERSITY OF SOUTH FLORIDA

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary examination report and its annexes, if any, established on the international application.
2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.
3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.
4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary examination report. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

DOCKETED

APR - 3 2001

T.L.B. IP. Dept.

APR 03 2001

C.J.L. IP. DEPT.

Name and mailing address of the IPEA/US

Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Authorized officer

PHAN T. H. PALMER

Facsimile No. (703) 305-3230

Telephone No. (703) 308-4848

Renee Palmer

Form PCT/IPEA/416 (July 1992)*

Mail II. 6/29/01

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference 21422/04017	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/US99/30774	International filing date (<i>day/month/year</i>) 22 DECEMBER 1999	(Earliest) Priority Date (<i>day/month/year</i>) 29 DECEMBER 1998
Applicant UNIVERSITY OF SOUTH FLORIDA		

This international search report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This international search report consists of a total of 3 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

a. With regard to the language, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

2. ☐ Certain claims were found unsearchable (See Box I).

3. ☐ Unity of invention is lacking (See Box II).

4. With regard to the title,

☒ the text is approved as submitted by the applicant.

☐ the text has been established by this Authority to read as follows:

5. With regard to the abstract,

☐ the text is approved as submitted by the applicant.

☒ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No. 1

☒ as suggested by the applicant.

☐ because the applicant failed to suggest a figure.

☐ because this figure better characterizes the invention.

☐ None of the figures.

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

NEW ABSTRACT

A liquid core waveguide (10) for fluorescence spectroscopy is provided. According to one version of the present invention, a substantially cylindrical support tube (30) is provided, having substantially constant outer diameter, and a flexible tube (12) is wrapped in contiguous windings about the outer surface of the support tube (30) to form a tight coil about the support tube (30) is configured of material that is transmissive of light in the relatively short wavelength range which is used to excite the molecular material in the flexible (12). This feature enables the flexible tube (12) to be wound tightly about the support tube (30) without crimping (thereby to form the liquid core waveguide into a compact package), and enables light in the relatively short excitation range to be effectively transmitted through the support tube (30) and into the flexible tube (12).

INTERNATIONAL SEARCH REPORT

International application No.
US99/30774

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :G02B 6/02; G01N 1/10

US CL :385/125, 12, 33; 356/246; 250/227.18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/125, 12, 33, 31, 32; 356/246, 301; 250/227.18, 227.14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS, SEARCH TERMS: LIQUID CORE\$1 AND COILS\$1; FLEXIBLE TUBE\$1, WRAP\$4 SAME WINDING SAME
SUPPORT TUBE\$1; GRIN LENS\$3

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — A	US 5,604,587 A (CHE et al.) 18 February 1997 (18-02-1997), See Figure 1 and Col. 3, Lines 49-65.	1-4 — 5-21
A,E	US 6,016,372 A (FEIN et al.) 18 January 2000 (18-01-2000), See Figure 3.	1-21

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

24 APRIL 2000

Date of mailing of the international search report

10 MAY 2000

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box FCT
Washington, D.C. 20231

Facsimile No. (703) 308-7724

Authorized officer

PHAN T. H. PALMER

Telephone No. (703) 308-4848

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under Article 19. The Notes are based on the requirements of the Patent Cooperation Treaty and of the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule" and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions, respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the international application may be amended ?

The claims only.

The description and the drawings may only be amended during international preliminary examination under Chapter II.

When ? Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments ?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How ? Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

What documents must/may accompany the amendments ?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confounded with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether:

- (i) the claim is unchanged;
- (ii) the claim is cancelled;
- (iii) the claim is new;
- (iv) the claim replaces one or more claims as filed;
- (v) the claim is the result of the division of a claim as filed.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 21422/04017	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/US99/30774	International filing date (<i>day/month/year</i>) 22 DECEMBER 1999	Priority date (<i>day/month/year</i>) 29 DECEMBER 1998
International Patent Classification (IPC) or national classification and IPC IPC(7): G02B 6/02; G01N 1/10 and US Cl.: 385/125, 12, 33; 356/246; 250/227.18		
Applicant UNIVERSITY OF SOUTH FLORIDA		

<p>1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.</p> <p>2. This REPORT consists of a total of <u>3</u> sheets.</p> <p><input type="checkbox"/> This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority. (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).</p> <p>These annexes consist of a total of <u>0</u> sheets.</p> <p>3. This report contains indications relating to the following items:</p> <ul style="list-style-type: none"> I <input checked="" type="checkbox"/> Basis of the report II <input type="checkbox"/> Priority III <input type="checkbox"/> Non-establishment of report with regard to novelty, inventive step or industrial applicability IV <input type="checkbox"/> Lack of unity of invention V <input checked="" type="checkbox"/> Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement VI <input type="checkbox"/> Certain documents cited VII <input type="checkbox"/> Certain defects in the international application VIII <input type="checkbox"/> Certain observations on the international application
--

Date of submission of the demand 31 JULY 2000	Date of completion of this report 23 MARCH 2001
Name and mailing address of the IPEA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer PHAN T. H. PALMER
Facsimile No. (703) 305-3230	Telephone No. (703) 308-4848 <i>Phan T. H. Palmer</i>

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/US99/30774

I. Basis of the report

1. With regard to the elements of the international application:*

- ☒ the international application as originally filed
- ☒ the description:
pages 1-16 , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of _____
- ☒ the claims:
pages 17-20 , as originally filed
pages NONE , as amended (together with any statement) under Article 19
pages NONE , filed with the demand
pages NONE , filed with the letter of _____
- ☒ the drawings:
pages 1-2 , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of _____
- ☒ the sequence listing part of the description:
pages NONE , as originally filed
pages NONE , filed with the demand
pages NONE , filed with the letter of _____

2. With regard to the language, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language _____ which is:

- ☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in printed form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. ☒ The amendments have resulted in the cancellation of:

- ☒ the description, pages NONE
- ☒ the claims, Nos. NONE
- ☒ the drawings, sheets/fig NONE

5. ☐ This report has been drawn as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).

**Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.

PCT/US99/30774

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**1. statement**

Novelty (N)

Claims 1-21

YES

Claims NONE

NO

Inventive Step (IS)

Claims 1-21

YES

Claims NONE

NO

Industrial Applicability (IA)

Claims 1-21

YES

Claims NONE

NO

2. citations and explanations (Rule 70.7)

Claims 1-21 meet the criteria set out in PCT Article 33(2)-(4), because the prior art does not teach or fairly suggest a liquid core waveguide device for fluorescence spectroscopy comprising a flexible tube for defining a liquid core and being transmissive to light in relatively short excitation wavelength range having an outlet end; a light coupling device connected to the outlet end and emitted light in a relatively longer wavelength range can pass, and a first light source configured to direct light in the relative short excitation wavelength range through the walls and into the liquid core of the flexible tube.

----- NEW CITATIONS -----

NONE

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/30774**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : G02B 6/02; G01N 1/10

US CL : 385/125, 12, 33; 356/246; 250/227.18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/125, 12, 33, 31, 32; 356/246, 301; 250/227.18, 227.14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS, SEARCH TERMS: LIQUID CORE\$1 AND COILS\$1; FLEXIBLE TUBE\$1, WRAP\$4 SAME WINDING SAME SUPPORT TUBE\$1; GRIN LENS\$3

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US 5,604,587 A (CHE et al.) 18 February 1997 (18-02-1997), See Figure 1 and Col. 3, Lines 49-65.	1-4 ----- 5-21
A,E	US 6,016,372 A (FEIN et al.) 18 January 2000 (18-01-2000), See Figure 3.	1-21

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

24 APRIL 2000

Date of mailing of the international search report

10 MAY 2000

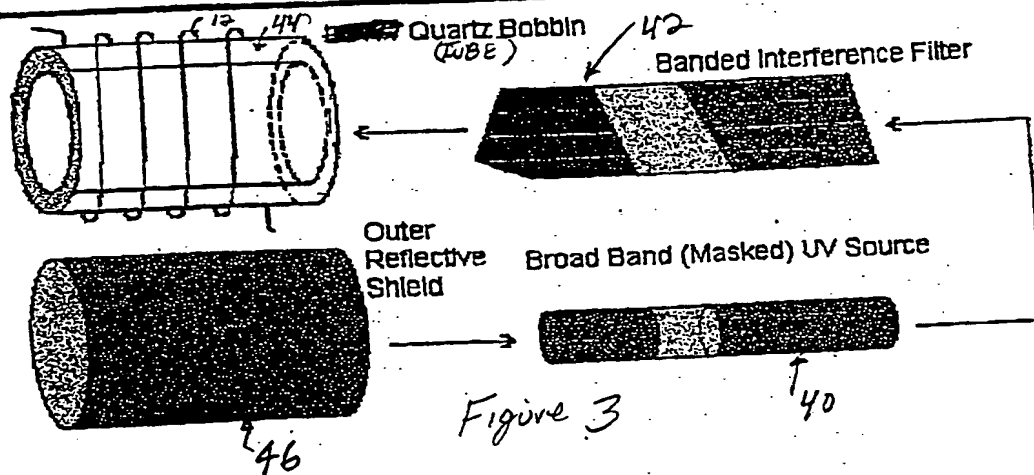
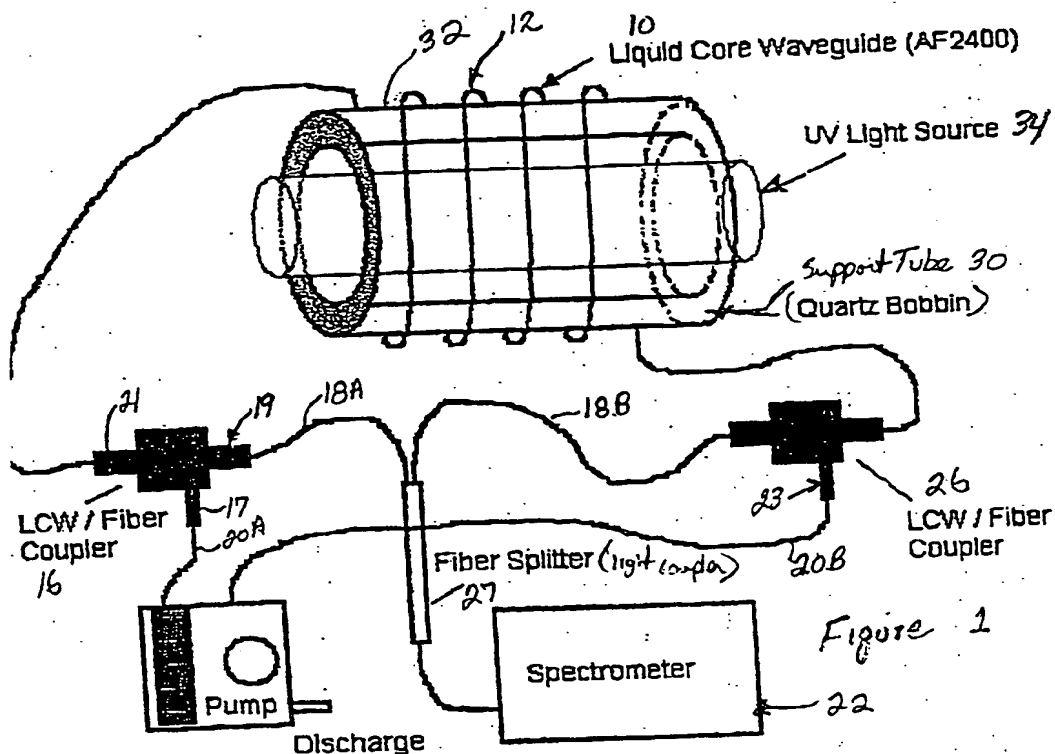
Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

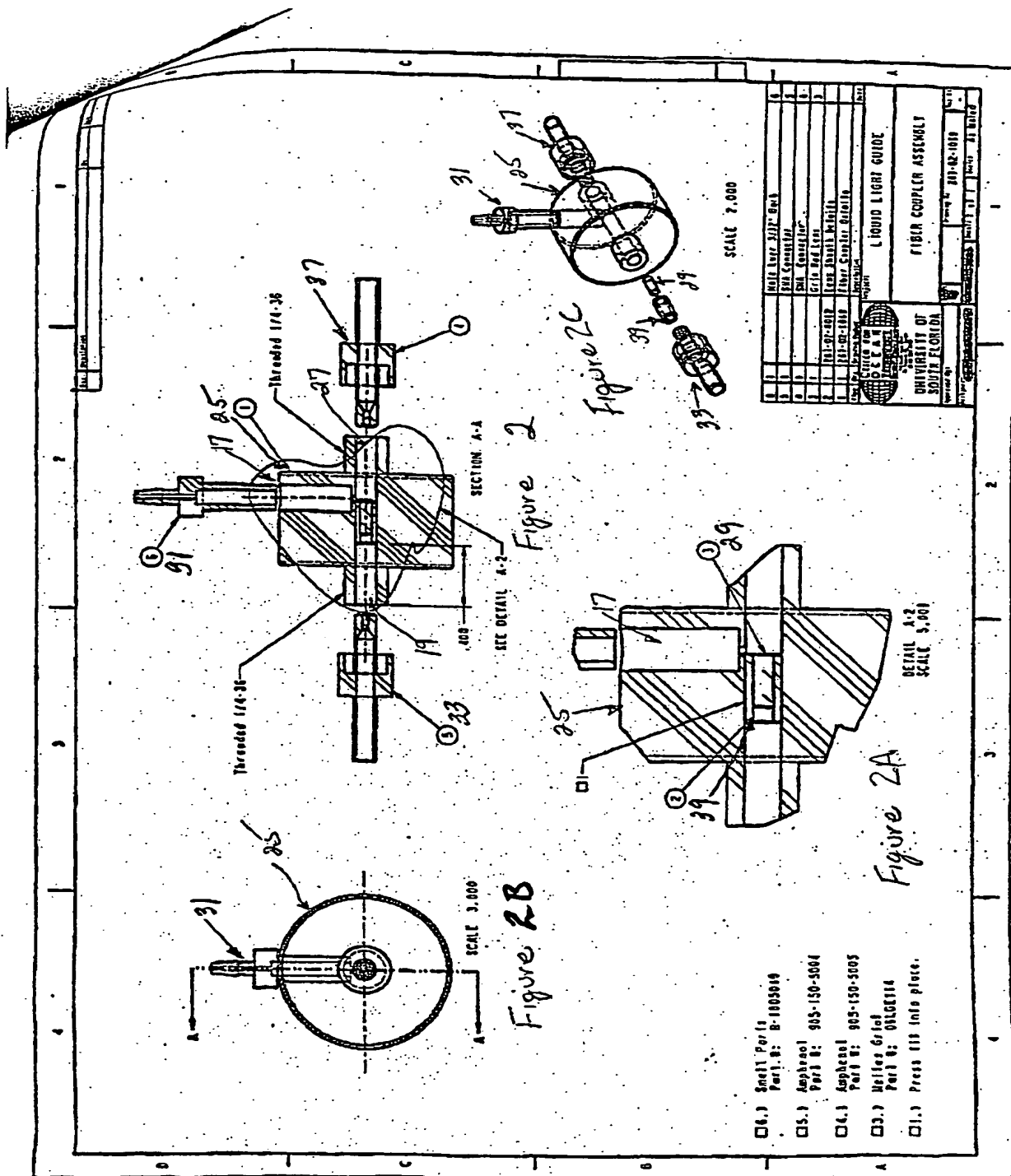
Facsimile No. (703) 308-7724

Authorized officer

PHAN T. H. PALMER

Telephone No. (703) 308-4846





PATENT COOPERATION TREATY

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

From the INTERNATIONAL BUREAU

To:

Commissioner
 US Department of Commerce
 United States Patent and Trademark
 Office, PCT
 2011 South Clark Place Room
 CP2/5C24
 Arlington, VA 22202
 ETATS-UNIS D'AMERIQUE
 in its capacity as elected Office

Date of mailing (day/month/year)
 17 November 2000 (17.11.00)

International application No.
 PCT/US99/30774

Applicant's or agent's file reference
 21422/04017

International filing date (day/month/year)
 22 December 1999 (22.12.99)

Priority date (day/month/year)
 29 December 1998 (29.12.98)

Applicant

KALTENBACHER, Eric et al

1. The designated Office is hereby notified of its election made:

☒ in the demand filed with the International Preliminary Examining Authority on:

31 July 2000 (31.07.00)

☐ in a notice effecting later election filed with the International Bureau on:

2. The election ☒ was

☐ was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO
 34, chemin des Colombettes
 1211 Geneva 20, Switzerland

Facsimile No.: (41-22) 740.14.35

Authorized officer

Kiwa Mpay

Telephone No.: (41-22) 338.83.38

CORRECTED VERSION

9/869653

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
6 July 2000 (06.07.2000)

PCT

(10) International Publication Number
WO 00/039615 A1

(51) International Patent Classification⁷: **G02B 6/02,**
G01N 1/10

(21) International Application Number: PCT/US99/30774

(22) International Filing Date:
22 December 1999 (22.12.1999)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/114,354 29 December 1998 (29.12.1998) US
60/114,212 29 December 1998 (29.12.1998) US

(71) Applicant (for all designated States except US): **UNIVERSITY OF SOUTH FLORIDA** [US/US]; 4202 E. Fowler Avenue FAO 126, Tampa, FL 33620-7900 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only):

KALTENBACHER, Eric [US/US]; 1945 Pelican Landing Boulevard #616, Clearwater, FL 33762 (US).
LANGEBRAKE, Lawrence, C. [US/US]; 12908 Lois Avenue, Seminole, FL 33776 (US). **BYRNE, Bob** [US/US]; 7472 17th Lane, N.E., St. Petersburg, FL 33702 (US). **WATERBURY, Robert** [US/US]; 727 House Wren Circle, Pal Harbor, FL 34683 (US).

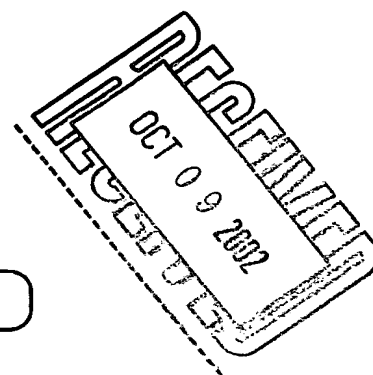
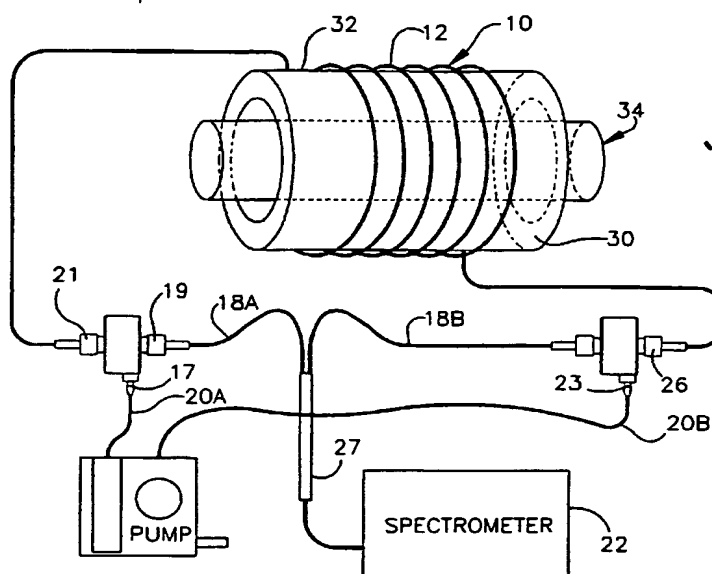
(74) Agent: **MILLER, John, E.**; Calfee, Halter & Griswold LLP, 1400 McDonald Investment Center, 800 Superior Avenue, Cleveland, OH 44114 (US).

(81) Designated States (national): AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW.

(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent

[Continued on next page]

(54) Title: FLUORESCENCE BASED LIQUID CORE WAVEGUIDE



(57) Abstract: A liquid core waveguide (10) for fluorescence spectroscopy is provided. According to one version of the present invention, a substantially cylindrical support tube (30) is provided, having a substantially constant outer diameter, and a flexible tube (12) is wrapped in contiguous windings about the outer surface of the support tube (30) to form a tight coil about the support tube (30) which is configured of material that is transmissive of light in the relatively short wavelength range which is used to excite the molecular material in the flexible tube (12). This feature enables the flexible tube (12) to be wound tightly about the support tube (30) without crimping (thereby to form the liquid core waveguide into a compact package), and enables light in the relatively short excitation range to be effectively transmitted through the support tube (30) and into the flexible tube (12).



WO 00/039615 A1



(AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

(48) Date of publication of this corrected version:

22 August 2002

(15) Information about Correction:

see PCT Gazette No. 34/2002 of 22 August 2002, Section II

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Fluorescence Based Liquid Core Waveguide

Government Support

A portion of the work described herein was supported by the Office of Naval Research under Contract No. N0014-96-1-5011.

Technical Field

The present invention relates to a liquid core waveguide and particularly to a liquid core waveguide for fluorescence spectroscopy.

Background

In earlier International Application PCT/US99/09395 (Publication No. WO 99/57584) entitled "*Liquid Core Waveguide*," there is disclosed a new and useful liquid core optical waveguide which is particularly suitable for long pathlength absorbance spectroscopy. The waveguide is formed from flexible tubing having a flexibility and structural integrity allowing it to be coiled into a small volume without crimping. By this means, waveguides having long optical pathlengths can be provided in very compact spaces.

Summary of the Present Invention

In accordance with the present invention, it has now been discovered that liquid core waveguides of the type described in the above-noted International Application PCT/US99/09395 and having long optical pathlengths in very compact spaces can also be made especially for use in emission spectroscopy such as fluorescence spectroscopy and the like.

In accordance with the present invention, a liquid core waveguide (LCW) comprises a flexible tube providing a liquid core and a light coupling for at least one end of the flexible tube. The flexible tube (i) has a substantially circular cross section and a substantially constant diameter, (ii) an index of refraction less than the index of refraction of a liquid which is disposed in the flexible tube, and (iii) is made from a material such that a cylindrical tube made from such material and having a liquid core diameter of about 560 μ m, an outer diameter of about 800 μ m and a length of about 5 meters can be coiled within a volume space of about 1.57 cubic inches and support a body of aqueous medium over its length without crimping.

A liquid core waveguide device for fluorescence spectroscopy, according to one preferred version of the present invention, includes a liquid core comprising a flexible tube which is configured into a coil, and is transmissive to light in relatively short wavelengths (e.g. ultraviolet light). The flexible tube has at least one light outlet (or "light coupling device") through which longer wavelength light (e.g. visible light) can pass. A light source is disposed at least partially within the coil and is configured to direct light of a relatively short wavelength range into the flexible tube to excite molecular material in the liquid core. The flexible tube is configured to contain a portion of light emissions of a longer wavelength (e.g. visible light) from the excited molecular material in the liquid core and to direct such portion of longer wavelength light emissions toward the light outlet.

According to one version of the present invention, the flexible tube has a plurality of light outlets, each configured to transmit longer wavelength light emissions. Moreover, the flexible tube is configured to direct the portion of the light emissions toward each of said plurality of light outlets, and a light coupler is provided in communication with each of the plurality of light outlets. The light coupler is configured to couple the light emissions from the plurality of light outlets and to direct the coupled light emissions from the plurality of light outlets to a spectrophotometric device for analyzing such light emissions.

In another preferred version of the present invention each of the plurality of light outlets has a coupling device with a graded index (GRIN) lens for providing a predetermined profile to the light emissions exiting from each

respective light outlet. Moreover, the flexible tube has a liquid core with a substantially constant cross section circular inner diameter, the GRIN lens at each light outlet has a cylindrical profile with a circular cross sectional diameter which is greater than the circular cross sectional diameter of the flexible tube, and the GRIN lens at each light outlet is substantially coaxial with its respective light outlet. Thus, a substantial portion of the light emissions passing through such light outlet is captured by the GRIN lens associated with the light outlet.

Still further, according to another feature of the present invention, a substantially cylindrical support tube is provided, having a substantially constant outer diameter, and the flexible tube is wrapped in contiguous windings about the outer surface of the support tube to form a tight coil about the support tube. The light source is disposed at least partially within the support tube, and the support tube is configured of material that is transmissive of light in the relatively short wavelength range which is used to excite the molecular material in the flexible tube. This feature enables the flexible tube to be wound tightly about the support tube without crimping (thereby to form the liquid core waveguide into a compact package), and enables light in the relatively short excitation wavelength range to be effectively transmitted through the support tube and into the flexible tube.

In yet another aspect of the present invention, the light source is configured to allow selective control the wavelength of the ultraviolet light (or other light suitable to cause fluorescence) that is transmitted into the flexible tube. For example, the light source can comprise a light emitter (e.g. broadband or ultraviolet), and a light filter can be provided between the light emitter and the support tube, for controlling the wavelength range of light from the light emitter that is directed into the support tube. The light filter is moveable relative to the light source and the flexible tube, and includes a plurality of narrow band filters which enable selective control of the wavelength range of light within the excitation range which is transmitted from the light emitter to the flexible tube.

In still another aspect of the present invention, a liquid core waveguide capable of being used for both fluorescence spectroscopy and absorbance spectroscopy is provided. In this embodiment, flexible tubing transmissive to

ultraviolet light is arranged about an ultraviolet light source in the same way as described above in connection with the other embodiments of the invention. However, in this embodiment, a light source useful for absorbance spectroscopy (e.g. a source of visible light) is optically coupled to the connector at one end of the flexible tubing. When this device is used for fluorescence spectroscopy, it operates in much the same way as the other embodiments of this invention as described above in that light from the ultraviolet light source is transmitted into the flexible tubing and the fluorescence caused thereby is transmitted through the connector located at the other end of the flexible tubing for detection by a spectrometer attached thereto. In this mode of operation, the source of visible light is inactive. However, when this device is used for absorbance spectroscopy, the operation of the lights is reversed — i.e., the visible light source is turned on while the ultraviolet light source is turned off. Accordingly, in this mode of operation, visible light is transmitted through the coupling on one end of the flexible tubing into the liquid core therein and attenuated light is transmitted through the coupling on the other end of the flexible tubing for detection by the spectrometer optically coupled thereto in a manner like that occurring with the wave guides shown in International Application PCT/US99/09395. In both modes of operation, measurements of high sensitivity can be obtained with a very compact system.

When operated in the fluorescence mode, the light source of the inventive wave guide is preferably an ultraviolet source, and the support tube is formed of quartz or another material which is substantially transmissive to light in the ultra violet range. Moreover, the flexible tube is preferably formed of Teflon® AF-2400 or other material that is substantially transmissive to light in the ultra violet range. Most preferably, the flexible tube is made from a material such as Teflon® AF-2400 which is substantially transmissive to ultra violet light and which also has an index of refraction less than that of water.

In an optional embodiment of the invention, the coupling devices through which liquid is directed into and out of the flexible tube, and through which light emissions are directed out of the flexible tube, are preferably formed with a graded index (GRIN) lens according to the principles described in commonly assigned US Provisional Application Serial No. 60/114,212,

entitled *Coupling Device For Liquid Core Waveguide*, the disclosure of which is incorporated herein by reference. In this embodiment, each coupling device comprises a housing supporting a fluid connector, a light connector and a tube connector. The fluid connector is configured for attachment to a fluid conduit for directing liquid into or out of the tube. The light connector is configured for connection to a light conduit such as a light fiber for directing light to an analytical device such as a spectrometer. The tube connector is configured for connection to an end of the flexible tube, and a graded index (GRIN) lens is provided between the light connector and the tube connector to substantially focus light transmitted between the light connector and the flexible tube. The GRIN lens has a substantially cylindrical configuration, is supported in the coupling device in a co-axial relationship with the portion of the flexible tube disposed within the tube connector, and has a cross sectional area which is larger than the cross sectional area of the portion of the flexible tube disposed within the tube connector, whereby the GRIN lens, when disposed to transmit light passing from the portion of flexible tube to a light conduit is oriented to capture substantially all of the light passing through the outlet of the flexible tube.

A liquid core waveguide device according to this form of the present invention is particularly configured for fluorescence spectroscopy, and comprises a flexible tube of the type described above, in a length of no more than 2 meters, coiled tightly about a quartz cylinder. An ultra violet light emitter is disposed within the cylinder, and is oriented to direct ultra violet light outward and through the cylinder and flexible tube, to excite molecular material within the flexible tube. In accordance with known fluorescence principles, the molecular material fluoresces, emits light in the visible range, and a substantial portion of that emitted visible light is retained in the flexible tube and directed by the flexible tube toward one or more light connectors, each of which is supported by a coupling device of the type described above. In each coupling device, substantially all of the emitted visible light is captured and focused by the GRIN lens, and directed to a light fiber (or fibers) which in turn transmit it to an analytical device.

A fluorescence based liquid core waveguide, which selectively controls the bandwidth of the ultraviolet light directly into the flexible tube, according to a specific aspect of the present invention, is intended to be particularly versatile, in the sense that it provides for selective examination and analysis of liquid samples under a number of selectively chosen light excitation sources and with a variety of materials in the liquid disposed in the flexible tube.

Further features of the present invention will become further apparent from the following detailed description and the accompanying drawings.

Brief Description of the Drawings

Figure 1 is a schematic illustration of a liquid core waveguide system for fluorescence spectroscopy, according to the present invention;

Figure 2 is a partially exploded cross sectional view of a coupling device for use with a waveguide according to the present invention taken from the direction A-A of Figure 2-B;

Figure 2A is an enlarged, fragmentary view of the area A-2 of Figure 2;

Figure 2B is an end view of one of the coupling devices of the system of Figure 1, the other coupling device being similarly configured;

Figure 2C is a three-dimensional, partially exploded view of the coupling device of Figures 2, 2A and 2B; and

Figure 3 is a schematic illustration of a liquid core waveguide system, useful for fluorescence spectroscopy according to the present invention, and configured to control the band width of excitation light directed into the waveguide.

Detailed Description

Fluorescence Based Spectroscopy

As described above, the present invention relates to a liquid core waveguide device which is particularly useful in fluorescence spectroscopy, and whose principles may also be useful in other applications, e.g. other types of emission based spectroscopy. The present invention is described herein in a system for fluorescence spectroscopy.

Fluorescence based spectroscopy, as used herein, is intended to mean a system in which light having a relatively short wavelength (e.g. ultra violet light) excites molecular material in a liquid sample, and the excited molecular material emits light in a relatively longer wavelength (e.g. in the visible range). The principles of the invention are described herein in a system which utilizes an ultra violet light source and in which light in the visible range is emitted from the excited molecular material in the liquid sample. However, it will be clear to those skilled in the art that the principles of this invention can be utilized in a system with other forms of light source and with emitted light in a different wavelength range, so long as the system operates on the fluorescence principles described herein.

A system for fluorescence spectroscopy is illustrated in Figure 1. The system includes a liquid core waveguide 10 including a flexible tube 12 made of Teflon® AF-2400 (e.g. from Biogeneral), with an inner diameter of about to 560 μm and an outer diameter of about to 800 μm . A length of liquid the flexible tube 12, e.g. not exceeding 2 meters in length, is coiled about a cylindrical support tube 30 and placed in a chamber (not shown) which is configured to prevent ambient light coupling into the liquid core waveguide. Coupling devices, 16,26, each of which is configured according to Exhibit A, and described further below, is provided at each end of the tube 12. The coupling devices enable liquid samples to be directed into and out of the flexible tube, and are also designed to interface the liquid core waveguide 10 to light conduits comprising optical fibers 18A, 18B (e.g. Polymicro Technologies 150 μm core diameter), and liquid conduits 20A, 20B, each comprising a standard 5 mm ID silicon tube. One coupling device 16 provides a liquid connector 17 through which liquid is directed into the tube 12 (see Figure 2-A), a light connector 19, and a tube connector 21 for one end of the tube 12. The light connector 19 and the tube connector 21 are configured such that visible light from the tube 12 is directed to the optical fiber 18A through which visible light emissions from the tube 12 are directed to a spectrometer 22 (via a light coupler 27). A second coupling device 26 is disposed at the other end of the tube 12. The coupling 26 is similar to the coupling device 16 and includes a liquid connector 23 through which liquid is directed out of the tube 12, and a

light connector 25 through which visible light from the other end of the tube 12 is directed to optical fiber 18B, for transmitting visible light emissions from the tube 12 to the spectrometer 22 (also via the light coupler 27). The tube 12 has a substantially constant cross section over its entire length.

Also, flexible tube 12 has a substantially cylindrical configuration over its length. Thus, the liquid core has a substantially circular cross section with an inner diameter which, in the preferred embodiment is preferably about $560\mu\text{m}$ and an outer diameter which, in the preferred embodiment is about $800\mu\text{m}$. Thus, the preferred wall thickness of the tube 12 is about $120\mu\text{m}$, and it is believed that the wall thickness of a length of tubing according to the preferred embodiment would be at least about $100\mu\text{m}$.

In the embodiment of Figure 1, the Teflon® AF 2400 flexible tube 12 is wound about the substantially cylindrical support tube 30, which is preferably made of quartz or other material which is transmissive to ultra violet light. The support tube 30 has a substantially smooth cylindrical outer surface 32, which enables the flexible tube 12 to be wound into tight contiguous windings about the support tube 30. This enables the flexible tube 12 to be formed into a relatively tight, compact package, without crimping.

Further, in the embodiment of Figure 1, an excitation light source, e.g. an ultra violet (UV) light source 34, is disposed within the cylindrical support tube 30. The UV light source 34 directs UV light radially outward, through the quartz tube 30 and the flexible tube 12, and into the liquid sample within the flexible tube 12. That UV light excites molecular material in the liquid sample causing the excited molecular material to fluoresce and emit light in a relatively longer wavelength (e.g. in this case to emit light in the visible range). A significant portion of such emitted light is confined within the flexible tube 12 and is directed toward the coupling devices 16,26 at the ends of the flexible tube 12. Further, in accordance with the invention, such visible light is captured and focused by a GRIN lens 29 in each coupling device (see Figures 2, 2A, 2B and 2C further described below), and directed to a respective optical fiber 18A, 18B. Still further, the emitted light conducted by the silicon light tubes 18A, 18B are combined (i.e. coupled) by the fiber splitter 27, and directed to an analytical light device such as the spectrometer 22.

According to another aspect of the present invention, the bandwidth of the UV light directed into the flexible tube 12 can be selectively controlled. Specifically, referring to Figure 3, a broadband (masked) UV light source 40 is disposed within a banded (prism shaped) interference filter 42. Both of these elements are disposed within a quartz support tube 44 and the flexible tube 12 is wound tightly in contiguous windings about the support tube 44. An outer reflective shield 46 can surround the support tube 44 and the windings of flexible tube 12. The outer reflective shield 46 reflects any UV light passing beyond the coils of the flexible tube back into the tube 12. With this embodiment, the interference filter 42 is moveable axially relative to the UV light source 40 and the support tube 44. As the filter 42 moves, it selectively controls the wavelength range of UV light which is transmitted to the flexible tube 12. This feature enables the system to be particularly versatile, in its ability to provide different types of analysis of different types of molecular materials in a liquid sample within the flexible tube.

Moreover, it is contemplated that the UV light source could be located outside the quartz support tube 44, and direct UV light emissions into the support tube 44, and a reflector inside the support tube 44 would reflect such UV light emissions radially outward through the quartz support tube 44 and into the flexible tube 12. In such a system, an interference filter similar to the filter 42 could be disposed between the reflector and the support tube, or outside the support tube and between the light source and the reflector. In this application, reference to a light source being located at least partially within the coiled flexible tube is intended to encompass all of the foregoing embodiments.

Accordingly, there is described above in a liquid core waveguide system for fluorescence based spectroscopy. Fluorescence based spectroscopy, as used herein, is intended to mean a system in which light having a relatively short wavelength (e.g. ultra violet light) excites molecular material in a liquid sample, and the excited molecular material fluoresces and emits light in a relatively longer wavelength (e.g. in the visible range). The principles of the invention are described herein in a system which utilizes an ultra violet light source and in which light in the visible range is emitted from the excited molecular material in the liquid sample. However, it will be clear to those skilled in the art that the

principles of this aspect of the invention can be utilized in a system with other forms of light source and with emitted light in a different wavelength range, so long as the system operates on the fluorescence principles described herein.

Optional Coupling Device

A coupling device that may be used for optically coupling the end of the flexible tubing used in wave guides of the present invention (whether in the fluorescence or absorbance modes) to a light source or detection device is schematically illustrated in Figures 2, 2A, 2B and 2C. As shown in these figures, coupling device 16 comprises a housing 25 preferably formed of Delrin® (DuPont) and has the liquid port 17, the light port 19 and a tube connector port 27 formed therein. The liquid port 17 is configured for attachment to a fluid connector 31 which in turn is adapted for connection to a fluid conduit (e.g. silicon tubing 20) for directing liquid into or out of the tube 12. The light port 19 is configured for connection to a light connector 33. The light connector 33 is configured to support a light conduit comprising one or more light fibers 18A connected to the light source. The tube connector port 27 is configured for connection to a tube connector 37 which, in turn, supports an end of the flexible tube 12. A graded index cylindrical (GRIN) lens 29 is disposed within a sheath 39 located in the housing 25. The liquid port 17 directs liquid into the coupling device at a location between the GRIN lens 29 and the tube connector 37 (see Figure 2A). Thus, the GRIN lens does not affect liquid flow into or out of the tube 12. The GRIN lens 29 functions to substantially focus light transmitted into the housing 25 through the light fiber(s) 18A and to direct the focused light into the flexible tube 12. In one embodiment GRIN lens 29 functions to collimate light transmitted into the housing 25 through the light fiber(s) 18A and to direct the collimated light into the flexible tube 12.

According to the preferred form of the present invention, the GRIN lens 29 and the end of the flexible tube are held in substantially fixed, coaxial relation to each other within the housing 25. The sheath 39 is configured for a tight fit with the interior wall of the housing, and the GRIN lens has a tight fit with the sheath 39, to maintain the GRIN lens 29 in fixed position in the housing 25. The tube connector port 27 tightly supports the tube connector 37

(e.g. by a threaded connection) and the tube connector 37 has an axial passage which tightly supports the end of the tube 12 in fixed coaxial relation to the GRIN lens 29. Moreover, the light connector 33 is tightly supported in the light port 19 (e.g. by a threaded connection), and the light connector 33 has an axial passageway which in turn tightly supports the light fiber(s) 18A in position in the light port 19. The cross section of the GRIN lens is substantially larger than the cross section of the light fiber(s) supported by the light connector 33, and the GRIN lens is located to extend across and radially beyond the light fiber(s) such that substantially all of the light transmitted through the light fibers(s) 18A is captured and focused by the GRIN lens. In the disclosed embodiment, the fluid connector 31 is a nose barb (Cole Palmer Part No. FK-06359-17), each of the light and tube connectors 33, 37 is an SMA connector (Amphenol Part No. 905-150-XXXX), and the GRIN lens 29 is a Melles Griot Part No. 06LGE114.

Similarly, the coupling device 26 at the outlet side of the flexible tube is configured such that its GRIN lens has a substantially cylindrical configuration, is supported in the coupling device 26 in a co-axial relationship with the portion of the flexible tube disposed within the coupling device, and has a cross sectional area which is larger than the cross sectional area of the portion of the flexible tube disposed within the coupling device, whereby the GRIN lens in the coupling device 26 is designed to capture and focus substantially all of the attenuated light exiting the flexible tube and to direct that attenuated light to the light fiber(s) which transmit the attenuated light to a light conduit (e.g. a light fiber 18B) for directing the attenuated light to an analytical device such as the spectrometer 22.

The coupling device 25 is preferably formed of a Delrin® material, and the flexible tube 12 is preferably formed from a material whose index of refraction is less than that of water such as Teflon® AF-2400 material.

Absorbance Spectroscopy Using a GRIN Lens

In one embodiment of the invention, a liquid core waveguide particularly configured for absorbance spectroscopy comprises a relatively long flexible tube as described above, with each end of the tube being provided with a coupling device having a GRIN lens as also described above. The coupling device at one end of the tube is configured to direct liquid from a pump such as

shown in Figure 1 into the flexible tube and the coupling device at the other end of the flexible tube is configured to direct liquid from the liquid core. Further, the coupling device at the one end of the flexible tube is configured such that electromagnetic radiation from a broadband light source can be directed into the tube and attenuated light can be directed from the other end of the flexible tube to an analytical device such as a spectrometer.

For absorbance spectroscopy, liquid core waveguide device would be designed with the flexible tube having a length of at least 20 cm, and preferably several meters (e.g. 5-10 meters) between its ends. Additionally, the flexible tube has a wall thickness of at least 100 μ m, and a ratio of length to liquid core volume that is greater than 300cm/cm³. Moreover, the GRIN lens has a length of about 5.4 mm., and a cross sectional diameter of about 1.8 mm., the light fiber(s) 18A and the flexible tube have cross-sectional diameters of less than the GRIN lens (e.g. the light fibers 18A including cladding have a cross sectional diameter of about 485 μ m, and the flexible tube inner diameter is about 560 μ m).

Sample solutions enter and exit the liquid core waveguide 10 through the liquid port 17 in the coupling device. A fiber-coupled light source 24 and a CCD array spectrometer 22 (e.g. Ocean Optics LS-1 Tungsten Halogen lamp and Ocean Optics S1000-TR-1 CCD array spectrometer) provide a broadband light source and spectral absorbance measurements, respectively, continuous sampling is achieved with a peristaltic pump 28(e.g. Ismatec, model 78016-30) at a flow rate of at least about 0.5 cm³/min. In order to avoid formation of bubbles in the system the pump 28 is active only during periods of sample introduction. Continuous pumping of sample however, easily flushes out bubbles inadvertently introduced to the system.

In order to perform absorbance spectroscopy, reagent(s) and sample(s) are combined to produce colored species that are introduced into the liquid core waveguide. Reagents are generally analytical-reagent grade. As an example, for analysis of Ferrous ion, ferrozine (Sigma) reagent can be used as a colorimetric reagent. Moreover, buffer solutions, (pH = 5.5) can be used to optimize color development. Absorbance measurements of each sample can be made relative to a reference solution containing no ferrozine reagent but identical to the sample solution in all other respects. Alternatively, reference solutions can be

constituted from natural solutions that have had all iron removed using ion exchange resins. The absorbance peak of the Fe(II)-ferrozine complex ($\text{Fe}(\text{FZ})_3$) at 562 nm (nanometers) can be used for the determination of Fe(II) concentration. The $\text{Fe}(\text{FZ})_3$ absorbance maximum coincides with water's transmission window (480 – 700 nm), thus minimizing the extent of light absorption by water. Absorbances are referenced to a non-absorbing wavelength (700 nm) in order to compensate for instrumental drift. Analysis of aqueous solutions for total dissolved iron ($\text{Fe}(\text{III}) + \text{Fe}(\text{II})$), rather than Fe(II) alone, can be accomplished by including a reductant (such as hydroxylamine hydrochloride) in the mixed buffer solution.

The sample size requirement for liquid core waveguide analysis is very low. For example, analysis with a 4 meter liquid core waveguide having a liquid core diameter of about 560 μm requires a sample size of less than 1.0 cm^3 . The practical upper limit pathlength for liquid core waveguide analysis appears to be substantially larger than 4 meters (i.e. 10 – 20 meters). Light throughput is not a limiting analytical parameter for pathlengths of this magnitude. Flow throughput with a 5 meter liquid core waveguide with a diameter of about 560 μm is about 2 minutes.

Moreover, a cylindrical Teflon® AF 2400 tube with a 560 μm inner diameter and 800 μm outer diameter, and a length of at least 5 m can be entwined within a volume space of 1.57 cubic inches and support an aqueous core over its length without crimping. "Entwined" is used to mean bent around multiple times in any manner, such as by way of example tightly coiled (little or no space between adjacent lengths), loosely coiled (more space between adjacent lengths), wound (as in thread wound around a spool or a length of rope wound), entwined in the ordinary sense (as in yarn entwined to form a ball of yarn), and haphazardly gathered into a "rats' nest." Thus, a long pathlength waveguide having the foregoing construction, can be housed in a relatively small volume space.

One of the most significant advantages of liquid core waveguide absorbance spectroscopic iron analysis, using a waveguide according to the present invention, is its substantial simplicity. Only one step, addition of combined reagent to a sample, is prerequisite to absorbance measurement. The

absence of preconcentration steps considerably lessens the potential for sample contamination. Thus, very low (sub nanomolar) iron concentrations can be measured with this technique.

Moreover, a liquid core waveguide having a length of about 4 meters, and an inner diameter of about 560 μ m, has an internal volume of less than 1 cm³ and a length to volume ratio of at least 400 cm/cm³. Thus, the length of tubing preferably has a ratio of length to liquid core volume that is ideally greater than 400 cm/cm³ but given manufacturing tolerances, as a practical matter a ratio of length to liquid core volume that is greater than 300 cm/cm³ is believed to be useful for practicing absorbance spectroscopy with a system according to the principles of the present invention. In any event, it should be clear that relatively small sample sizes are required for conducting long pathlength absorbance spectroscopy according to the principles of the present invention.

The principles of the present invention can be used to markedly extend the detection capabilities of many existing solution-based measurements obtained via absorbance spectroscopy. The analytical apparatus required for this analysis is very simple and robust. The overall analysis is quite amenable to miniaturization and autonomous in-situ analysis.

Fluorescence and Absorbance Spectroscopy Combined in Same Device

In still another aspect of the present invention, a liquid core waveguide capable of being used for both fluorescence spectroscopy and absorbance spectroscopy is provided. This device has a structure essentially the same as the device illustrated in Figure 1, except that the distal end of optical fiber 18A, rather than being connected to spectrometer 22 as shown in Figure 1, is connected to a source of broadband radiation such as a visible light source (not shown).

When this device is used for fluorescence spectroscopy, it operates in essentially the same way as the embodiment of Figure 1 in that light from ultraviolet light source 34 is transmitted into flexible tubing 12 and the fluorescence caused thereby is transmitted through the coupling device 26 located at the outlet end of the flexible tubing and through optical fiber 18 B for detection by spectrometer 22. In this mode of operation, the source of visible

light is inactive. However, when this device is used for absorbance spectroscopy, the operation of the lights is reversed — i.e., the visible light source (not shown) is turned on while the ultraviolet light source is turned off. Accordingly, in this mode the device operates in a manner similar to the device of International Application PCT/US99/09395 in that broadband light (e.g. visible light) from the light source is transmitted through optical fiber 18A and coupling device 19 into the liquid being analyzed in flexible tubing 12, while attenuated light produced inside flexible tube 12 is then transmitted through coupling device 26 and optical fiber 18 B for detection by spectrometer 22. In both modes of operation, measurements of high sensitivity can be obtained with a very compact system. Nonetheless, both modes of operation, fluorescence and absorbance, are combined in a single device. This provides an especially attractive combination of simplicity, versatility, compactness and accuracy in an important analytical tool widely used in science and industry.

The Flexible Tubing

It should be noted that it is useful to describe the flexibility and structural integrity of a length of tubing forming a liquid core waveguide according to the invention by referring to certain parameters of the preferred embodiment (i.e. that a length of tubing having a length of about 5 meters, a liquid core cross section diameter of about 560 μ m, and an outer diameter of about 800 μ m could be entwined in a volume space of about 1.57 cu. in. and support an aqueous medium over its length without crimping). However, such a parametric description of the tubing is believed to be useful in describing the type of tubing, in terms of flexibility and integrity with which the present invention can be implemented, but is not intended to limit the invention to tubing of those exact dimensions, other than may be recited in specific claims of this application. For example, tubes having cores 200 μ m to 1mm in diameter and outer diameters of 500 μ m to 2mm are also useful in accordance with the present provided they also have qualities of flexibility and integrity allowing entwinement of a 5 meter length of the tube in a small space without crimping as described above.

In addition, while the invention has been described above in terms of lengths of tubing in the range of 4 meters, 5-10 meters and longer, it is also

contemplated that long pathlength absorbance spectroscopy can be practiced effectively with liquid core waveguides as short as 20 cm, and 1 meter in length, and also with liquid core waveguides on the order of several meters, 5-10 meters, and longer, using the principles of the present invention.

Claims

1. A liquid core waveguide device for fluorescence spectroscopy, comprising
 - a) a flexible tube for defining a liquid core and being transmissive to light in a relatively short excitation wavelength range, the flexible tube having on at least one outlet end,
 - b) a light coupling device connected to the outlet end of the flexible tube through which emitted light in a relatively longer wavelength range can pass, and
 - c) a first light source configured to direct light in the relatively short excitation wavelength range through the walls and into the liquid core of the flexible tube to excite molecular material in the core.
2. The liquid core wave guide of claim 1, wherein the flexible tube is configured into a coil and wherein at least a portion of the first excitation light source is arranged in the coil.
3. The liquid core wave guide of claim 2, wherein the first light source is capable of generating ultraviolet light of a wavelength suitable to cause fluorescence of a material in the liquid core.
4. The liquid core waveguide of claim 2, further comprising a support tube, the flexible tube being wrapped in windings about the outer surface of the support tube to form a tight coil about the support tube, wherein the light source is disposed at least partially within the support tube, and wherein the support tube is configured of material which is transmissive of light in the relatively shorter excitation wavelength range.
5. The liquid core waveguide of claim 4, including a filter device configured to selectively control the wavelength range of the relatively shorter wavelength excitation light which is transmitted into the flexible tube.
6. The liquid core waveguide of claim 5, wherein the filter is disposed between the first light source and the flexible tube, and the filter includes a plurality of narrow band filters which enable selective control of the wavelength range of light within the excitation range which is transmitted from the light source to the flexible tube.
7. The liquid core waveguide of claim 5, wherein the filter is disposed between the first light source and the flexible tube, and the filter is moveable relative to the support tube.
8. The liquid core waveguide of claim 4, wherein the first light source comprises a light emitter disposed outside of the support tube and disposed to direct light in the excitation

range into the support tube, and further wherein a reflector is provided within the support tube for redirecting light from the emitter toward the flexible tube.

9. The liquid core waveguide of claim 1,
wherein both ends of the flexible tube are provided with light coupling devices, each configured to enable light emissions to pass there through,
wherein the flexible tube is configured to direct a portion of the light emissions toward each light coupling device, and

wherein a light splitter is provided in communication with each light coupling device, the light couplers being configured to couple the light emissions from respective light coupling devices and to direct the coupled light emissions to a spectrophotometric device for analyzing such light emissions.

10. The liquid core waveguide of claim 1, wherein each light coupling device has a graded index (GRIN) lens for providing a predetermined profile to the light passing therethrough.

11. The liquid core waveguide of claim 10, wherein the flexible tube has a core with a substantially constant cross section circular inner diameter, the GRIN lens at each light coupling device having a cylindrical profile with a circular cross sectional diameter which is greater than the circular cross sectional diameter of the flexible tube, and wherein the GRIN lens at each light coupling device is substantially coaxial with its respective light coupling device, whereby a substantial portion of the light emissions passing through the light coupling device is captured by the GRIN lens associated with the light coupling device and directed to the light coupler.

12. The liquid core waveguide of claim 1, wherein both ends of the flexible tube are provided with a light coupling device through which emitted light in a relatively longer wavelength range can pass, the waveguide further comprising a second light source capable of generating broadband electromagnetic radiation, the second light source being optically connected to the light coupling device on the end of the flexible tube opposite the outlet end whereby light from the second light source can be directed into the core of the flexible tube and attenuated light produced in the core can be directed through the outlet end of the flexible tube for analysis.

13. The liquid core wave guide of claim 12, wherein the flexible tube is configured into a coil and wherein at least a portion of the first excitation light source is arranged in the coil.

14. The liquid core wave guide of claim 13, wherein the first light source is capable of generating ultraviolet light of a wavelength suitable to cause fluorescence of a material in the liquid core.

15. The liquid core waveguide of claim 14, further comprising a support tube, the flexible tube being wrapped in windings about the outer surface of the support tube to form a tight coil about the support tube, wherein the light source is disposed at least partially within the support tube, and wherein the support tube is configured of material which is transmissive of light in the relatively shorter excitation wavelength range.

16. The liquid core waveguide of claim 12, wherein the first and second light sources can be individually activated whereby the waveguide can be used for fluorescence spectroscopy by activating the first light source and deactivating the second light source and, in addition, be used for absorbance spectroscopy by activating the second light source and deactivating the first light source.

17. A liquid core waveguide system comprising a flexible tube and a coupling device providing a liquid and a light coupling for at least one end of said flexible tube, said flexible tube (i) having a substantially circular cross section and a substantially constant diameter, and (ii) having an index of refraction less than the index of refraction of a liquid which is disposed in the flexible tube, the coupling device comprising a housing and a graded index (GRIN) lens to substantially focus light transmitted between said light conduit and the end of the flexible tube.

18. The liquid core waveguide of claim 17, wherein the flexible tube is configured into a coil, and wherein the GRIN lens and the end of the flexible tube are held in substantially fixed, coaxial relation to each other within the coupling device.

19. The liquid core waveguide of claim 18, wherein a portion of the flexible tube is disposed within the coupling device and further wherein the GRIN lens has a substantially cylindrical configuration and a cross-sectional area which is larger than the cross-sectional area of the portion of the flexible tube disposed within the coupling device, whereby the GRIN lens is oriented to capture substantially all of the light passing through the coupling device.

20. The liquid core waveguide of claim 19, wherein the coupling device defines a fluid port, a light port and a tube connector formed therein,

1/2

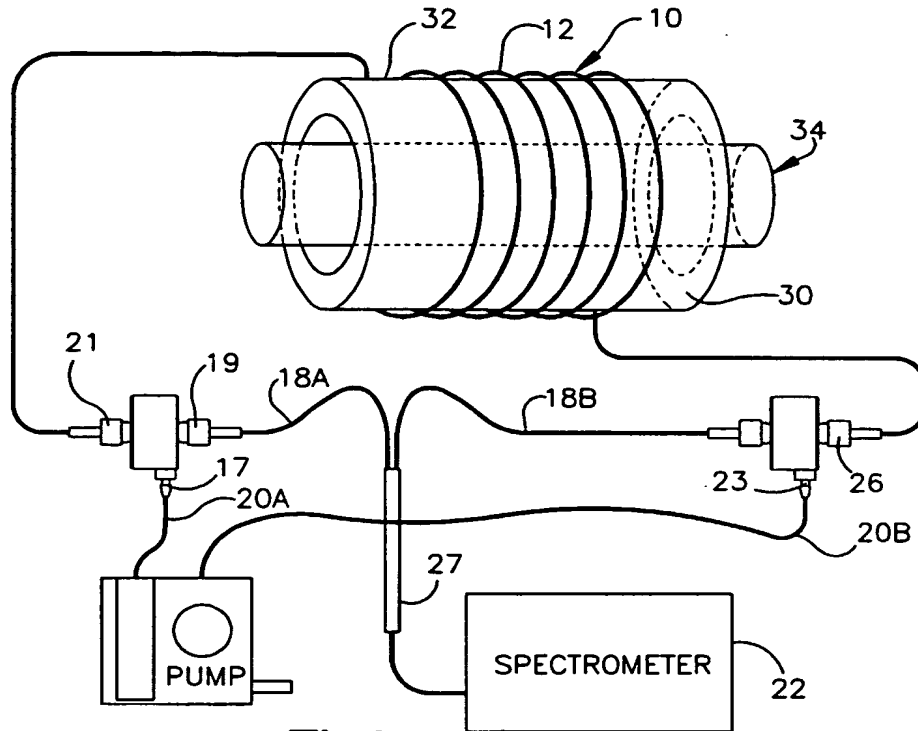


Fig.1

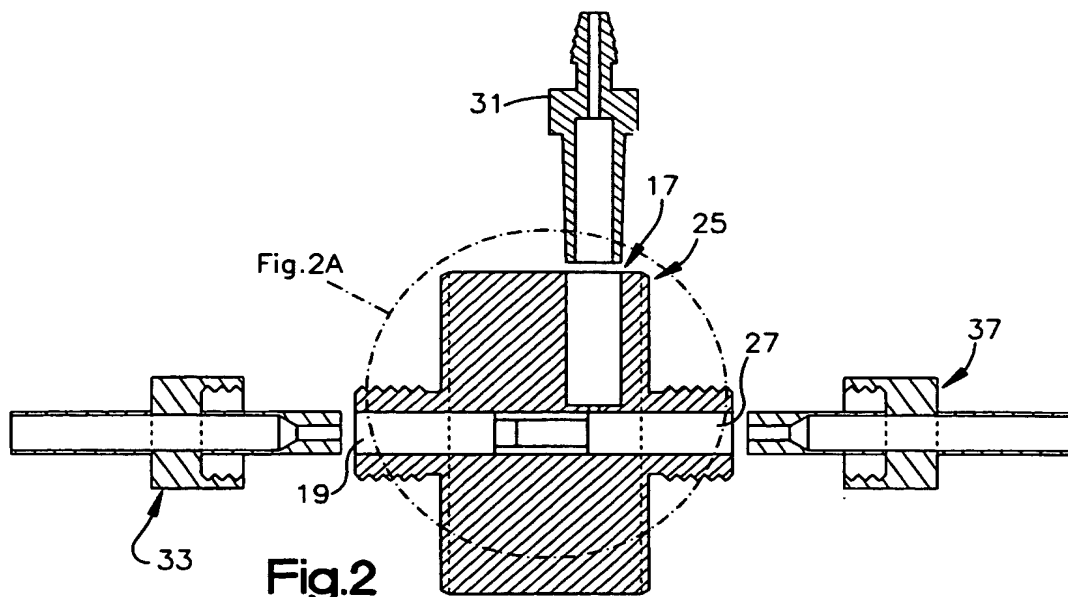


Fig.2

2/2

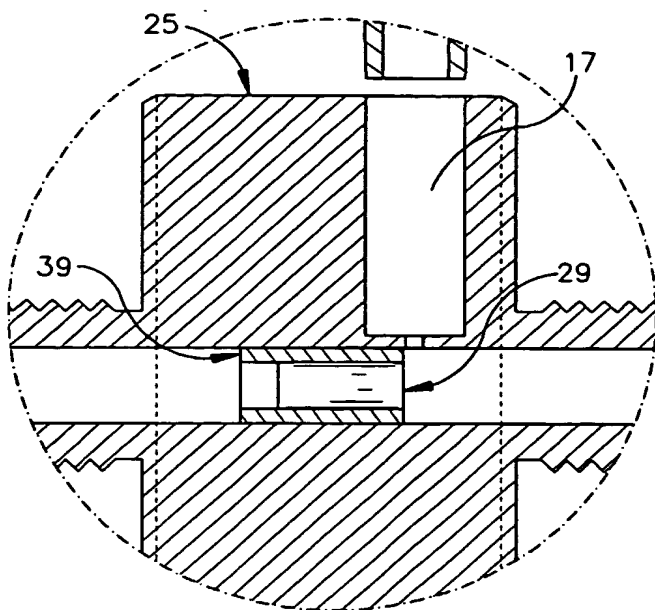


Fig. 2A

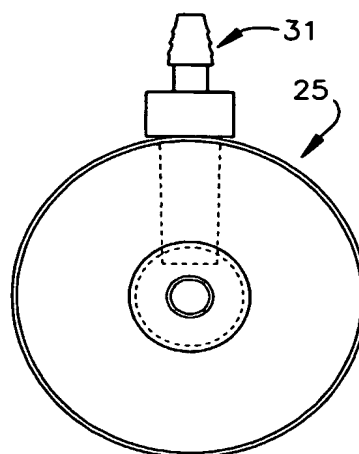


Fig. 2B

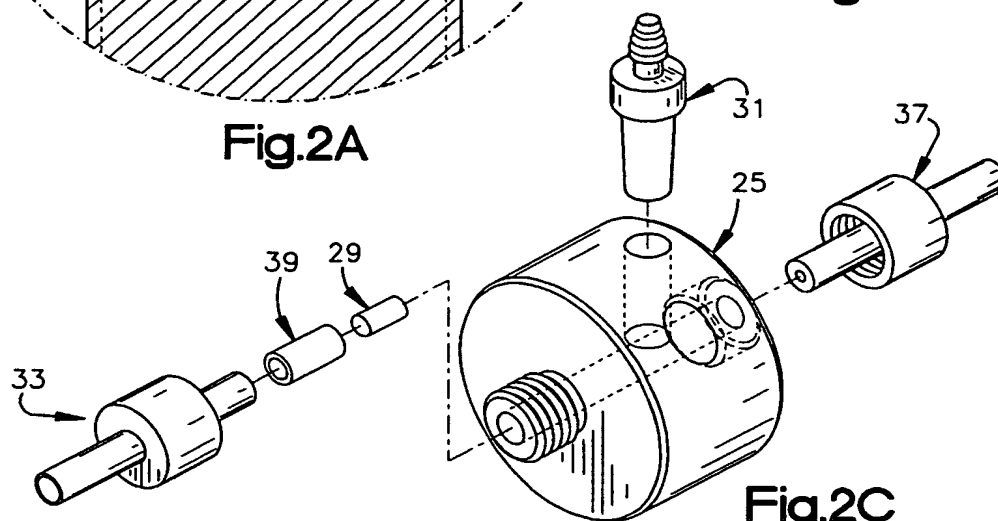


Fig. 2C

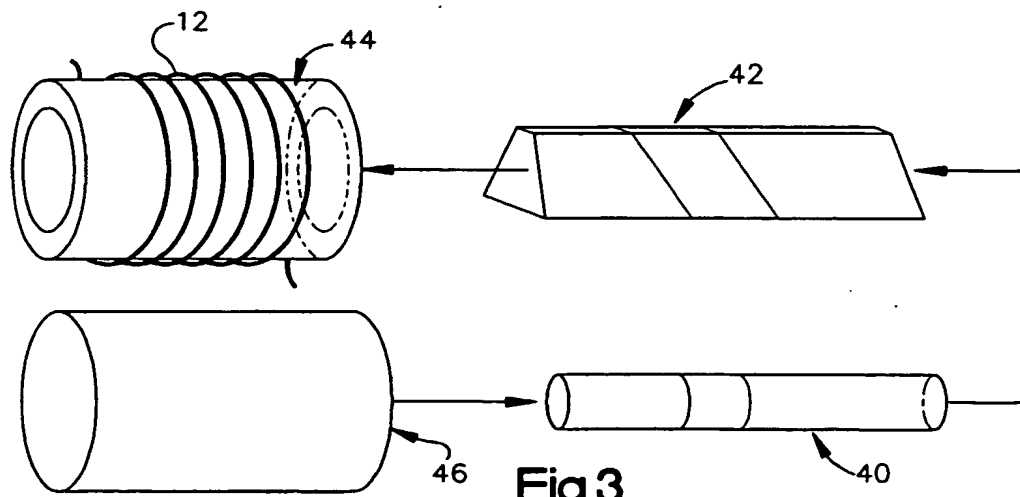


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/30774

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G02B 6/02; G01N 1/10

US CL : 385/125, 12, 33; 356/246; 250/227.18

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 385/125, 12, 33, 31, 32; 356/246, 301; 250/227.18, 227.14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS, SEARCH TERMS: LIQUID CORE\$1 AND COILS\$1; FLEXIBLE TUBES\$1, WRAP\$4 SAME WINDING SAME SUPPORT TUBES\$1; GRIN LENS\$3

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- A	US 5,604,587 A (CHE et al.) 18 February 1997 (18-02-1997), See Figure 1 and Col. 3, Lines 49-65.	1-4 ----- 5-21
A,E	US 6,016,372 A (FEIN et al.) 18 January 2000 (18-01-2000), See Figure 3.	1-21

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

24 APRIL 2000

Date of mailing of the international search report

10 MAY 2000

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 308-7724

Authorized officer

PHAN T. H. PALMER

Telephone No. (703) 308-4846